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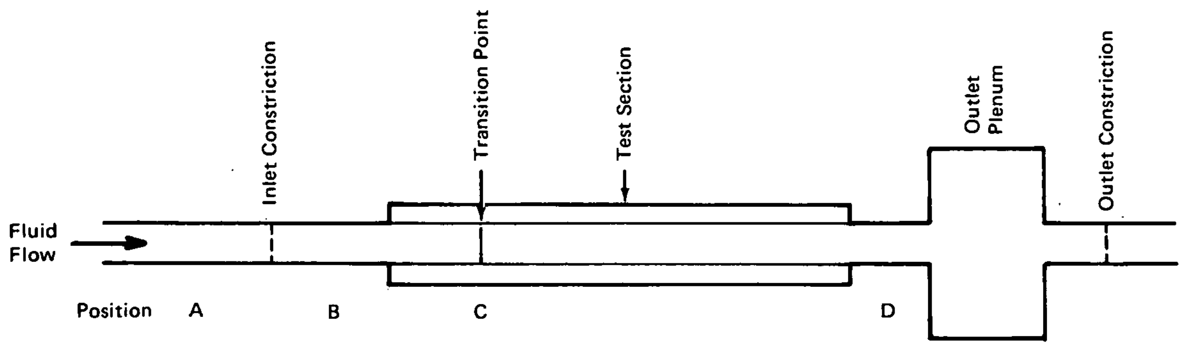
NASA TECH BRIEF

Marshall Space Flight Center

Thermal Induced Flow Oscillations in Heat Exchangers for Supercritical Fluids



The problem:

When a cryogenic fluid is heated close to its critical point as it passes through the heat exchanger, it produces severe flow oscillations. This instability phenomenon can be detrimental to the system operation. A concise investigation is needed to predict the conditions under which these events occur and how to minimize them. With this information, a designer can prevent potentially unstable heat-exchanger configurations.

The solution:

An analytical model has been developed to predict the possible unstable behavior in supercritical heat exchangers. It is found that the rate of the heat transfer plays an important role in the stability of the system. From the complete model, a greatly simplified stability criterion is derived. This criterion states that, for stability, a ratio of stabilizing to destabilizing pressure drops in the fluid must be greater than the fluid expansion factor. As a result of this criterion, the stability of a heat-exchanger system can be predicted in advance.

How it's done:

A simplified drawing of a fluid in motion is shown in the figure. The fluid flows through a tube from left to right. Between positions A and B, there is a constriction before the test section is reached. In the test section between points C and D, the fluid is heated from an external source. Downstream from the test section is a plenum and another constriction.

The dynamic state of the fluid in the test section can be completely defined by a series of equations which relate to continuity, fluid-energy momentum, wall energy, and wall boundary conditions. Adhering to the normal procedure for stability analysis, these equations are solved for small perturbations about the steady-state values of the variables. The test-section pressures will then be related to the pressure drops in the rest of the system. This will yield the system response to any external stimulus, such as the upstream pressure. A steady-state solution will then be unstable if the perturbation variables increase exponentially as a result of any disturbance.

After the pressure drops for the entire system are formulated in the steady and perturbed states, the total system response to an external pressure is derived. This is called the characteristic equation for the system and determines its stability. In addition, by the use of Nyquist plots, the characteristic curves can be analyzed to determine whether the system is unstable.

(continued overleaf)

The use of the complete characteristic equation and the Nyquist diagram to predict the system stability is a cumbersome procedure. Although this procedure can be automated, it is still desirable to apply a much simpler criterion. By making some approximations to the characteristic equation, a simplified stability criterion equation can be formulated. It includes the effects of up-stream and down-stream orifices and the acceleration and friction pressure drops in the test section. It does not include the inertia or body-force pressure drops.

This criterion and its equation are documented for general use.

Notes:

1. It is recommended that this criterion be used as a guide in designing stable supercritical heat exchangers. Since the available data do not seem to point out all the limitations of the criterion, more data are needed. Therefore, it is recommended that the controlled laboratory experimentation be performed to further confirm or disprove the utility of the criterion.

2. Requests for further information may be directed to:
   Technology Utilization Officer
   Marshall Space Flight Center
   Code A&PS-TU
   Marshall Space Flight Center, Alabama 35812
   Reference: B72-10598

Patent status:

NASA has decided not to apply for a patent.

Source: J. C. Friedly, J. L. Manganaro, and P. G. Krueger of General Electric Company under contract to Marshall Space Flight Center (MFS-21262)